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SOME RESULTS FROM CONTROLLED TESTING BY STIFFENING ELEMENT IN THE 18MN PRESS

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SOME RESULTS FROM CONTROLLED TESTING BY STIFFENING ELEMENT IN THE 18 MN PRESS

by

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ABSTRACT

In this brief note the details of a parallel stiffening element for use in Elliot Lake Laboratory's Gilmore 18 MN (4×10^6 lbf) press are given. Initial tests suggest post-failure behaviour can be controlled under conditions of constant loading rate by this method. Not being a servo-controlled press, the actuator in the Gilmore machine moves essentially without intelligence during failure, which it is believed, more nearly represents reality.

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INTRODUCTION

The Gilmore press can be represented by the four stiffness elements, Fig. 1. Element P_3 is the 'parallel stiffener' which is intended to convert the press (stiffness) to a mine (stiffness).

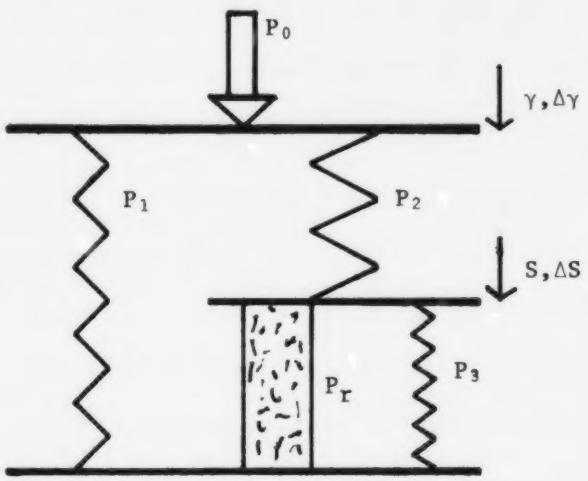

Fig. 1 - Stiffness configuration for post-failure tests with parallel stiffener.

The equilibrium conditions are: $P_0 = P_1 + P_2$

and $P_2 = P_r + P_3$

Also: $\Delta P_0/\Delta t = \text{constant}.$

Now, the stiffness of each element is known, given by:

$$\Delta P_1/\Delta\gamma = k_1$$

$$\Delta P_2/\Delta(\gamma-S) = k_2$$

$$\Delta P_3/\Delta S = k_3$$

$$\Delta P_r/\Delta S = k_r$$

At the stage of post-failure it is essential for stability that in a virtual displacement the energy to be released from the loaded frame is always less than that to be absorbed by the rock and stiffener, i.e.:

$$\Delta W_r + \Delta W_3 > \Delta W_2$$

$$(P_r + \tfrac{1}{2}\Delta P_r)\Delta S + (P_3 + \tfrac{1}{2}\Delta P_3)\Delta S > (P_2 + \tfrac{1}{2}\Delta P_2)\Delta(\gamma - S)$$

and, $$k_r \Delta S + k_3 \Delta S > k_2 \Delta(\gamma - S)$$

Now, if, for small $\Delta P_0/dt$, $\Delta\gamma \to 0$

stability requires: $$k_r + k_3 = k_S > -k_2 \qquad \text{Eq 1}$$

Clearly, in a pillar failure model, while stability is not an a priori condition, roof stiffness, which is, may be modelled by the equality:

$$\Delta\gamma/_{press} = \Delta\gamma/_{mine}$$

In a servo-controlled frame k_3 is not active as in the present sense; k_2 is made more negative by making $\Delta\gamma$ negative. This, however, is more a manipulation of Equation 1 than an attempt to model a process.

An illustration of the load-deformation behaviour through post-failure of the various elements in Fig. 1 is given in Fig. 2. Linear relationships are assumed for simplicity.

PARALLEL ELEMENT DESIGN

In preparing the design of the stiffener the following steps were taken:

- determine maximum specimen size to be controlled. For a 18 MN press, 20% or less may be available to the rock specimen. While this figure can be greater the tolerances necessary to achieve a given stiffness k_3 at failure are much finer (contact surfaces must be finely polished, etc.). Thus, maximum failure load of the rock is 3.6 MN. Next, taking a compressive strength of 200 MPa as typical,

  specimen diameter, D, $\leq$ 150 mm

  specimen length, L, = 2.5 D = 380 mm.

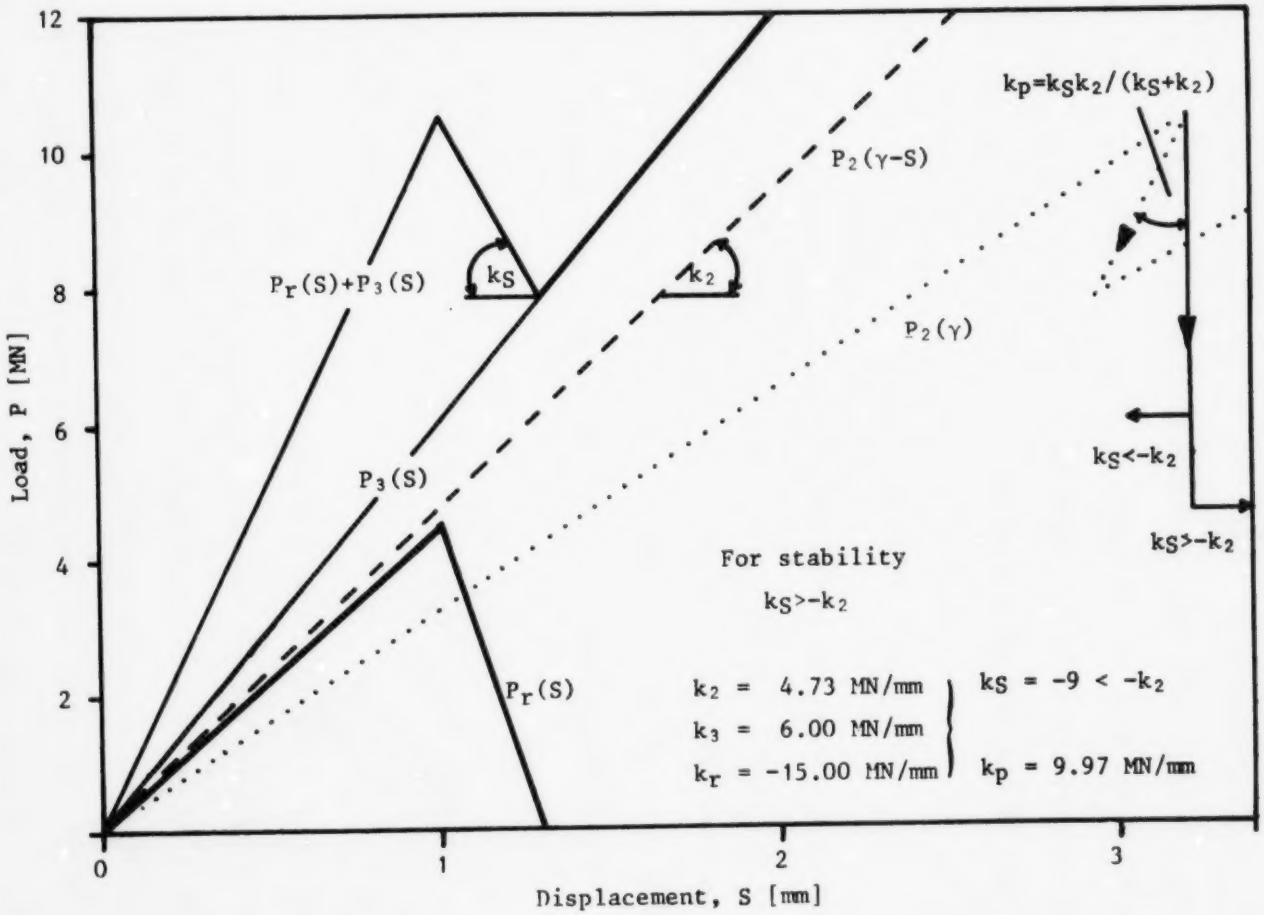

Fig. 2 - Load-deformation curves for various elements in Fig. 1 (schematic only).

- determine stiffener's dimension. For hot-rolled AISI 1020 mild steel, yield stress $\simeq$ 207 MPa.

  Maximum load available to stiffener is (18-3.6) = 14.4 MN and cross-sectional area, $A_3 = 69.6 \times 10^{-3}$ m^2.

  Next, using $k = \Pi(D/2)^2E/L$, the stiffness of this element, k_3, will be of the order of 38 MN/mm at maximum load. This would appear to be a considerable improvement on, say, the situation where k_3 = 6 MN/mm, see Fig. 2. Based upon the area 69.6×10^{-3} m^2, the stiffener's radial dimensions will be given by:

$$A_3 = \frac{\Pi}{4}(D_1^2 - D_2^2) = 69.6 \times 10^{-3} \text{ m}^2$$

  [D_1 = external diameter; D_2 = internal diameter].

Allowing for the possibility of some confining pressure medium in the element, an internal diameter D_2 of 275 mm (11 inches) was chosen. D_1 was then determined to be 406 mm (16 inches).

The element's length was taken equal to the rock specimen, 380 mm (15 inches).

STIFFNESS MEASUREMENTS

PRESS STIFFNESS

Measurement of k_2 to include the effects of oil compression in the hydraulic system is most easily achieved by measuring actuator deformation when the press is loaded via, say, a triaxial cell. In the present case a 40 MPa triaxial cell was available which could apply a maximum load of nearly 4 MN. For k_2 beyond this load, extrapolation was necessary, see Fig. 3. From this a maximum value for k_2 was taken as 6 MN/mm.

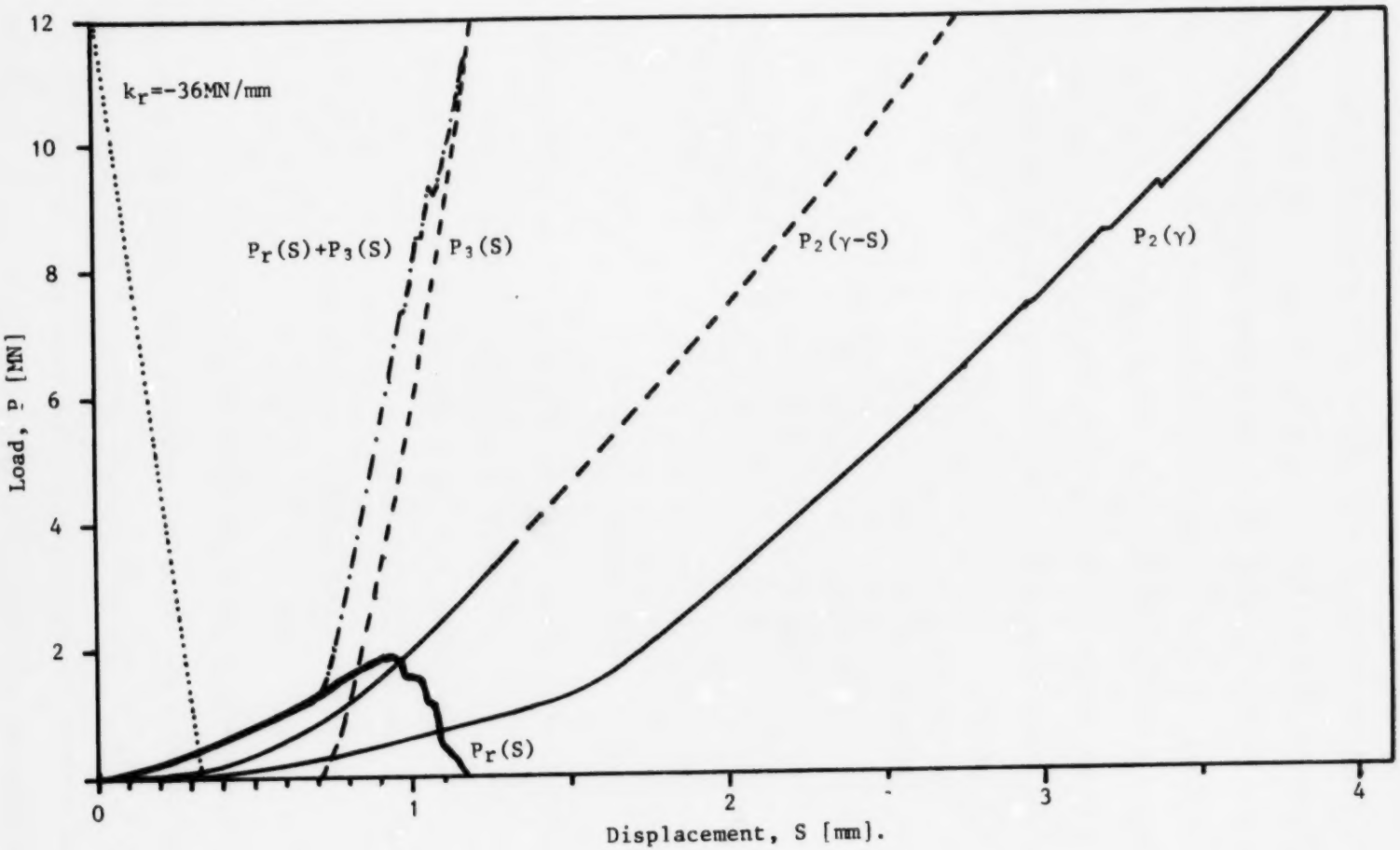

Fig. 3 - Experimental load-deformation curves for South Mine specimen # 1. The dotted line shows the limiting k_r value for which stability exists.

PARALLEL ELEMENT STIFFNESS

The stiffness of the parallel element with dimensions given above and with ends ground parallel to ± 25 μm was measured. Repeated loadings showed a scatter in the response. Since the element before each test will be uniquely positioned and possibly two or three loadings of the specimen may be necessary before achieving failure (after adding shim), $P_3(S)$ for a given test is uncertain within limits. These limits have been carefully recorded so that for a given test the actual $P_3(S)$ may be identified. A maximum value of k_3 was taken as 30 MN/mm.

ROCK (FAILURE) STIFFNESS

For stability the condition:

$$-(k_3 + k_r) < k_2 \quad \text{is true,}$$

and $$k_r > -30 - 6 > -36 \text{ MN/mm.}$$

This is shown as a dotted line in Fig. 3.

POST-FAILURE EXPERIMENTS

A limited volume of core was available on which to perform some initial experiments. Two specimens were prepared from INCO's South Mine orebody stress measurement overcores; the second specimen was made up in two lengths. Dimensions were nominally:

$$L = 359 \text{ mm}; \quad D_1 = 143 \text{ mm}; \quad D_2 = 38 \text{ mm}$$

$$A_r = 15.03 \times 10^{-3} \text{ m}^2$$

The specimen's ends were ground carefully to be parallel ± 25 μm.

After cleaning all contacting surfaces, the test was set up as shown schematically in Fig. 4. The rock-element overlap, while critical, cannot be pre-determined without some uncertainty. This means that the rock should preferably be prepared undersize, since brass shim can easily be introduced

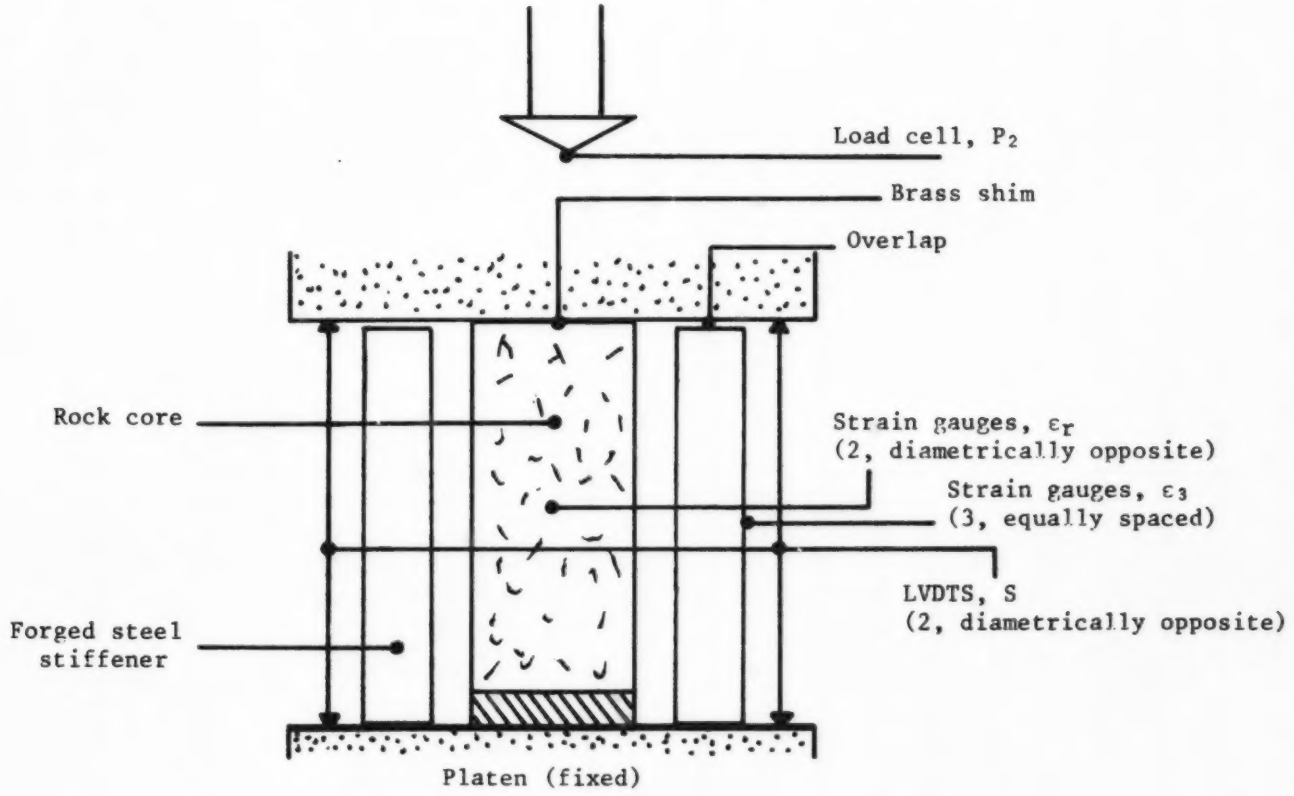

Fig. 4 - Test set-up prior to loading specimen (schematic).
All surfaces are parallel to within ± 25 μm.

subsequently to increase the overlap. The optimum overlap for the present specimens was found to be about 0.7 mm, Fig. 3.

Observing the variables, $\overline{S}$, $\overline{\varepsilon}_3$, $\overline{\varepsilon}_r$ and P_2, the specimens were loaded quickly at first, but then slowly (11.5 MN/hour) as failure was approached. Even this speed may be too fast, but press modifications are necessary to achieve one slower. During failure, to simulate a mine pillar-roof response, the press continued to load, albeit slowly. Displacement rates of the specimen ends were not measured, though the time-dependency of the process, both modelled and real, suggests this should in fact be done.

Following the complete specimen collapse, the element is loaded for a short interval to determine the appropriate k_3 behaviour (see above) and then unloaded, still observing $\overline{S}$, $\overline{\varepsilon}_3$ and P_2 ($\overline{\varepsilon}_r$ cannot be observed for $\sigma_r >$ compressive strength).

RESULTS

Knowing $P_3(S)$ and $P_2(S)$, the discrete force-displacement diagram $P_r(S)$ can be deduced for the rock specimen using:

$$P_r(S_i) = P_2(S_i) - P_3(S_i - S_{overlap});\ S_i > S_{overlap}$$

The result for specimen # 1 is shown graphically in Fig. 3.

This result may be supplemented by evaluating a stress-strain diagram for the rock, knowing $P_3(\varepsilon_3)$ and $P_2(\varepsilon_3)$. Taking the stress and strain at the instant of zero overlap as σ_{ro} and ε_{ro} respectively, at

$$(\varepsilon_r - \varepsilon_{ro}) \simeq \varepsilon_3 = \varepsilon_i$$

and for $\sigma > \sigma_{ro}$

$$\sigma_r(\varepsilon_r)A_r = P_2(\varepsilon_i) - P_3(\varepsilon_i)$$

If strain gauges are glued to the rock specimen then $\sigma_r(\varepsilon_r)$ ($\sigma_r <$ compressive strength) can be used to provide a value for ε_{ro}, σ_{ro} being taken from the $P_2(\varepsilon_3)$ data. Thus the complete (apparent) stress-strain diagram $\sigma_r(\varepsilon_r)$

for the rock can be evaluated discretely in a similar way to the force-displacement diagram.

Results for both specimens are summarized in Fig. 5. The failed specimen # 1, is shown as removed from the press (the stress cell acting to hold it together) in Fig. 6.

CONCLUSIONS AND RECOMMENDATIONS

The use of a parallel stiffening element in the Elliot Lake Laboratory's 18 MN Gilmore press has enabled the post-failure testing of large (<10 inch diameter) cores. It appears that rocks with mean post-failure stiffnesses greater than -36 MN/mm may now be controlled. Effective press capacity is still great, in the order of 4 MN.

In order to judge the appropriateness of the machine's failure response the following could still be done:

1. modify press loading rate mechanism to achieve slower rates during failure (<0.8%/min).
2. measure γ, and the time derivatives $\dot{\gamma}$ and $\dot{S}$ during failure and compare with mine data (not necessarily available).

In addition the following suggestions are made:

1. Use multiple pillars and/or a single pillar with variable w/h ratio.
2. Use a fill material in the space between rock and stiffening element and investigate confining effects on pillar stability.

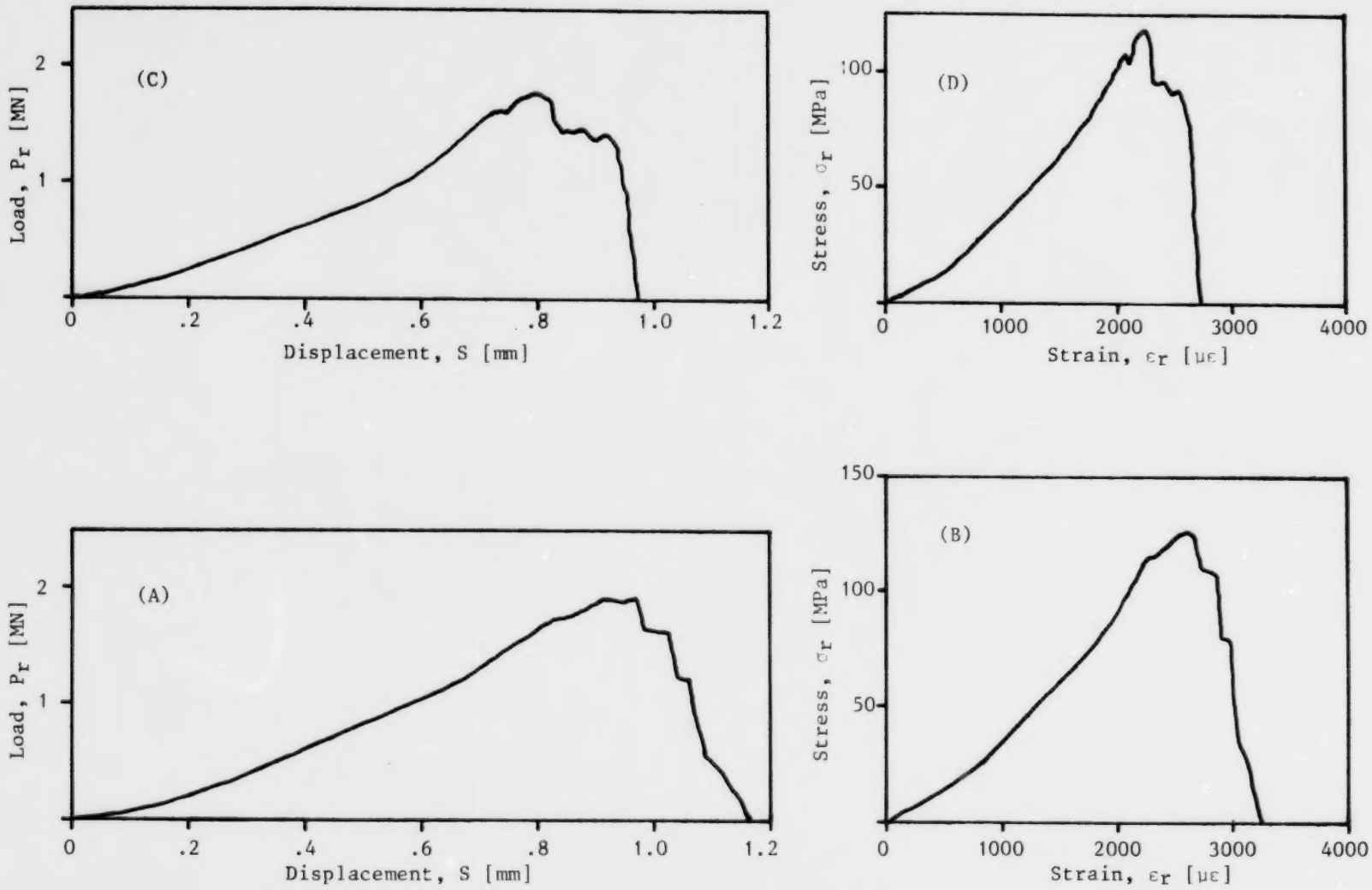

Fig. 5(A), (B) - Load-displacement, stress-strain curves for specimen 1; South Mine, 1250L orebody.
(C), (D) - Load-displacement, stress-strain curves for specimen 2; South mine, split 1500L/ 1250L orebody.

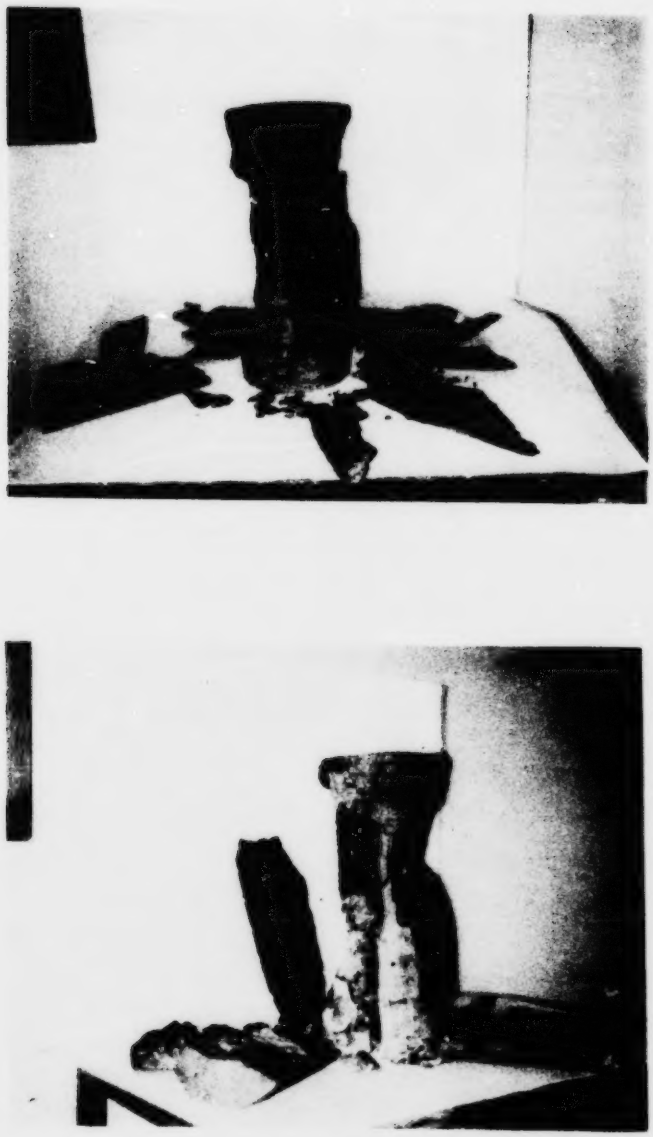

Fig. 6 - Appearance of specimen 1 immediately following controlled test. The remnants are held together by the unbroken stress cell.